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Design of a water channel to model the wave conditions in the Colombian Pacific Ocean

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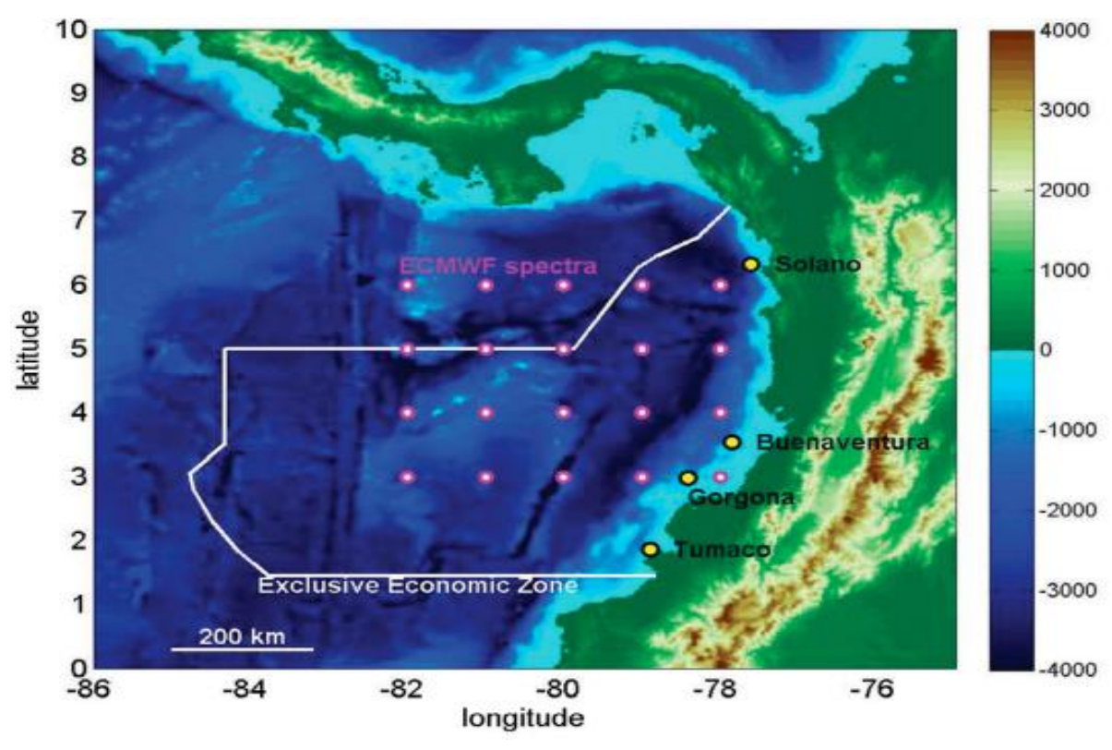
During the design process of an efficient wave energy converter (WEC), a crucial aspect is its performance evaluation in wave channels able to generate dynamic waves simulating the ocean conditions. This work presents the design of a water channel that simulates the wave conditions of the Pacific Ocean in Colombia. The designed channel has a rectangular cross-section with width, length and depth equal to 0.49 m, 7.35 m and 1.47 m, respectively. In the channel, the steepness ratio can vary from 0.0134 to 0.544 for a wavelength of 1.47 m.

Keywords: Wave energy, hydrodynamic modelling, wave channel

Material and methods

Objective

The aim of this work is to design a wave channel able to model regular wave trains in deep and intermediate water with similar characteristics as the Colombia Pacific Ocean conditions to create innovative and reliable WECs locally for transforming the wave energy into useful energy.



Location	Wave height mean (H, m)	Wave period mean (T, s)	Mooring water depth (d, m)
Tumaco	1.01	6.86	146
Gorgona Island	1.13	7.76	135
Buenaventura Harbour	0.96	8.21	150
Solano Bay	1.17	10.61	130

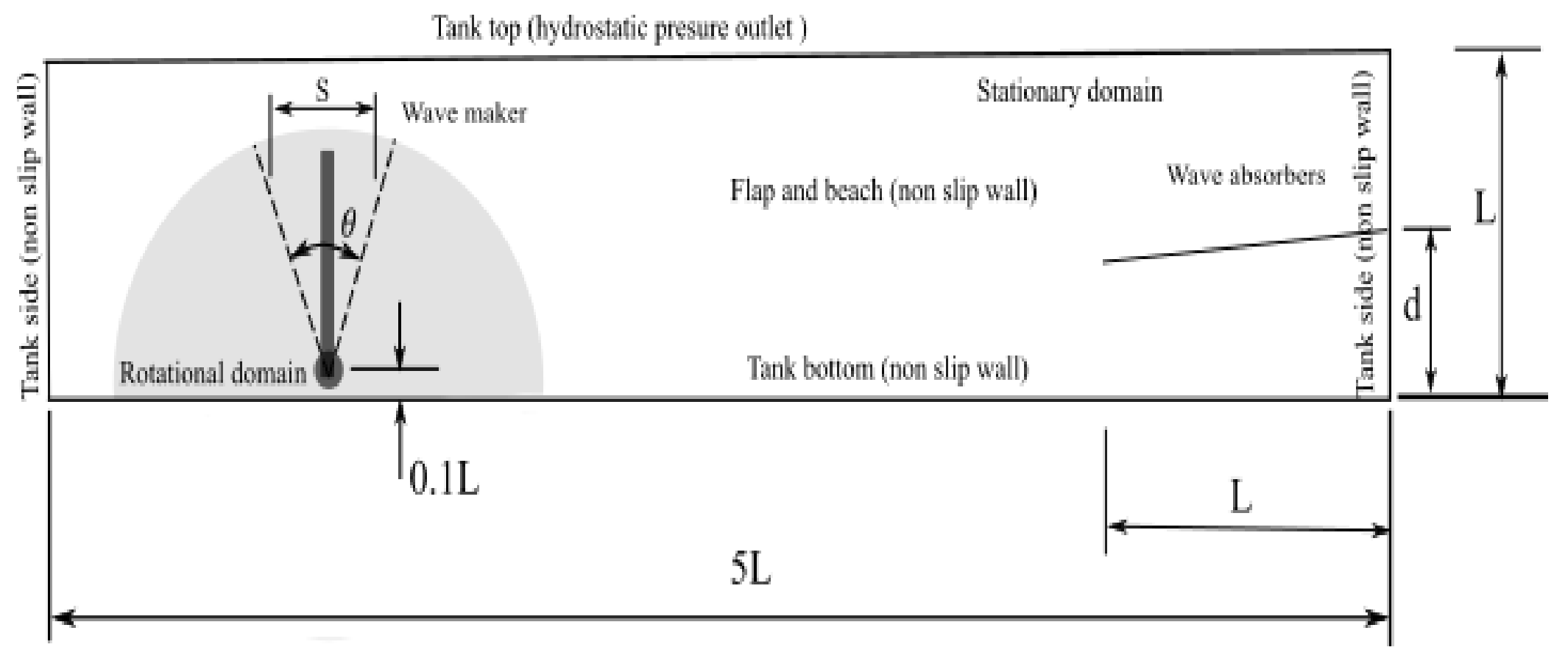
Identifying wave characteristics . Data of the waves generated in the Colombian Pacific Ocean.
Source: Portilla et al. 2015

For the design of the wave channel, the limit values were analysed, which coincided with the pairs: i) d_{min}, H_{min}-T_{max}, ii) d_{min}, H_{max}, T_{max}, iii) d_{max},, H_{max}-T_{min}, and iv) d_{max}, H_{min}-T_{min}.

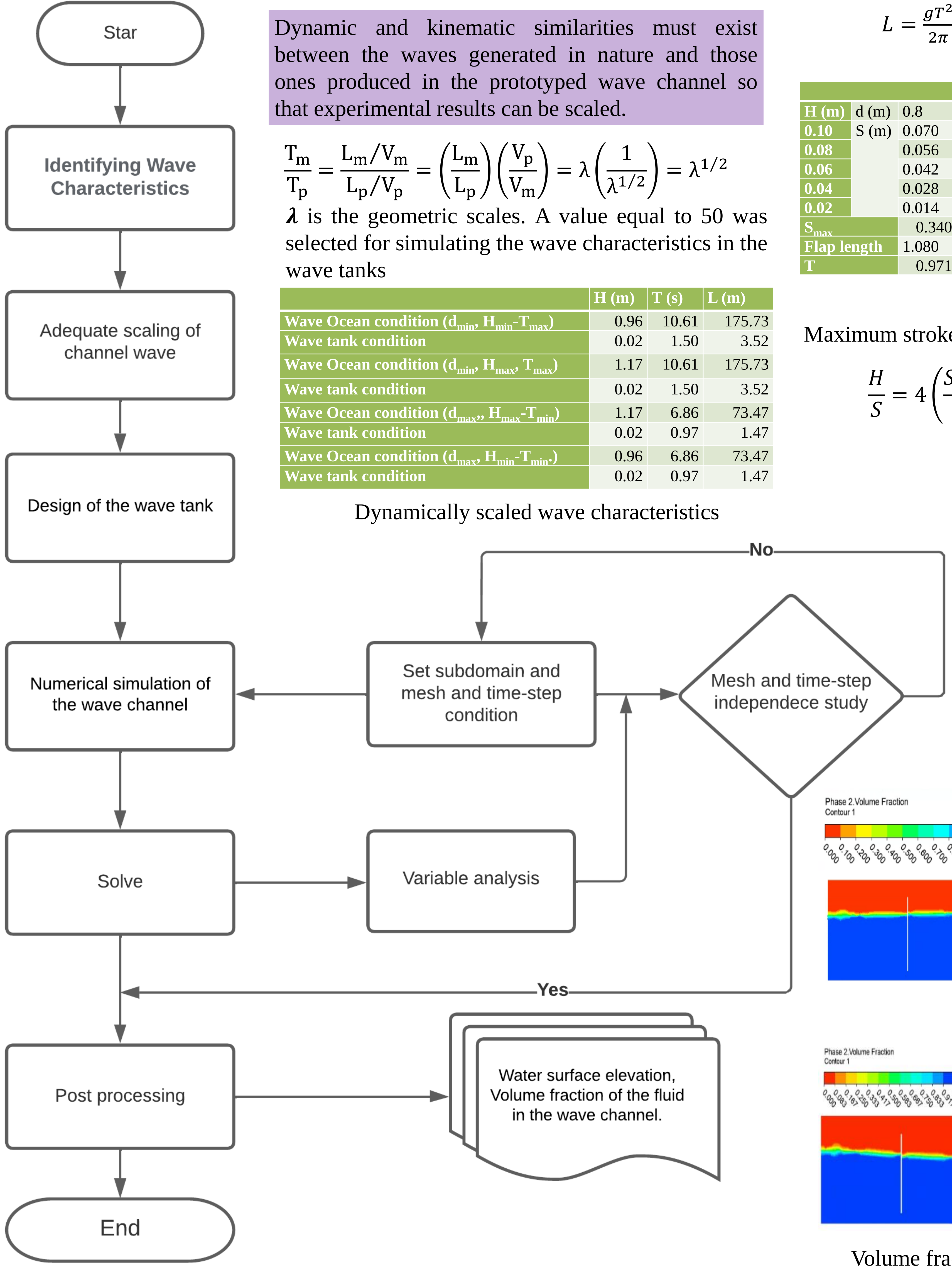
Setting	D (m)	H (m)	T (s)	L (m) for intermediate water	L (m) for deep water
d_{min}, H_{min}-T_{max}	130	0.96	10.61	175.73	176.76
d_{min}, H_{max}, T_{max}	130	1.17	10.61	175.73	175.76
d_{max},, H_{max}-T_{min}	150	1.17	6.86	73.47	73.47
d_{max}, H_{min}-T_{min}.	150	0.96	6.86	73.47	73.47

$$L = \frac{gT^2}{2\pi} Tanh\left(\frac{2\pi d}{L}\right) \text{ (intermediate water)}$$

$$L = \frac{gT^2}{2\pi} \text{ (Deep water)}$$



Determination of the wavelength (L)



Star

Identifying Wave Characteristics

Adequate scaling of channel wave

Design of the wave tank

Numerical simulation of the wave channel

Set subdomain and mesh and time-step condition

Mesh and time-step independece study

No

Yes

Solve

Variable analysis

Post processing

Water surface elevation, Volume fraction of the fluid in the wave channel.

End

Adequate scaling of the wave channel

Dynamic and kinematic similarities must exist between the waves generated in nature and those ones produced in the prototyped wave channel so that experimental results can be scaled.

$$\frac{T_m}{T_p} = \frac{L_m/V_m}{L_p/V_p} = \left(\frac{L_m}{L_p}\right)\left(\frac{V_p}{V_m}\right) = \lambda\left(\frac{1}{\lambda^{1/2}}\right) = \lambda^{1/2}$$

λ is the geometric scales. A value equal to 50 was selected for simulating the wave characteristics in the wave tanks

	H (m)	T (s)	L (m)
Wave Ocean condition (d_{min}, H_{min}-T_{max})	0.96	10.61	175.73
Wave tank condition	0.02	1.50	3.52
Wave Ocean condition (d_{min}, H_{max}, T_{max})	1.17	10.61	175.73
Wave tank condition	0.02	1.50	3.52
Wave Ocean condition (d_{max},, H_{max}-T_{min})	1.17	6.86	73.47
Wave tank condition	0.02	0.97	1.47
Wave Ocean condition (d_{max}, H_{min}-T_{min}.)	0.96	6.86	73.47
Wave tank condition	0.02	0.97	1.47

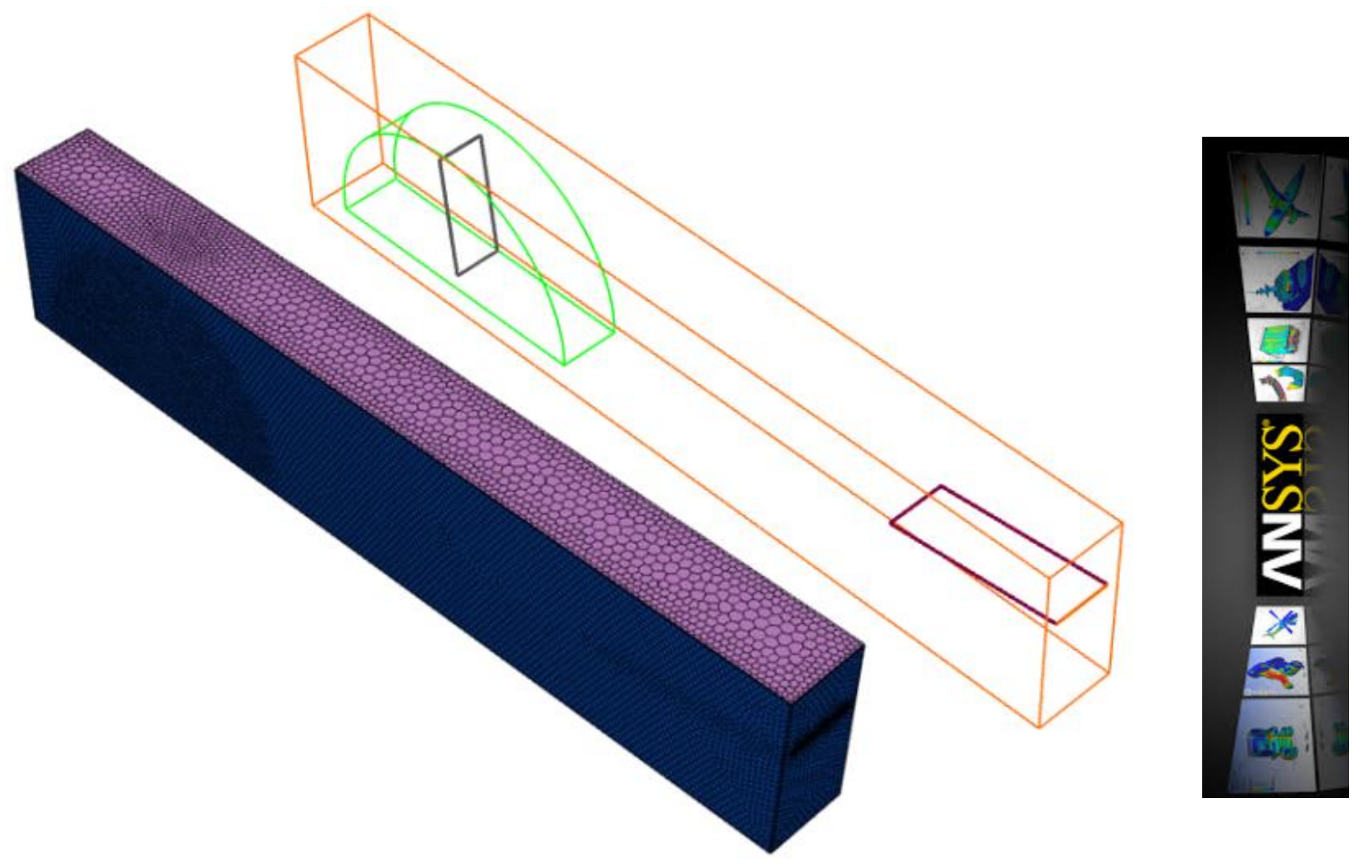
Dynamically scaled wave characteristics

L=1.47 m									
H (m)	d (m)	0.8	0.7	0.6	0.5	0.4	0.3	0.2	0.1
0.10	S (m)	0.070	0.074	0.081	0.091	0.110	0.146	0.224	0.461
0.08		0.056	0.059	0.064	0.073	0.088	0.117	0.179	0.369
0.06		0.042	0.045	0.048	0.055	0.066	0.088	0.134	0.277
0.04		0.028	0.030	0.032	0.036	0.044	0.058	0.089	0.185
0.02		0.014	0.015	0.016	0.018	0.022	0.029	0.045	0.092
S_{max}		0.340	0.298	0.255	0.213	0.170	0.128	0.085	0.043
Flap length		1.080	0.945	0.810	0.675	0.540	0.405	0.270	0.135
T		0.971	0.973	0.976	0.984	1.003	1.048	1.165	1.528

Maximum stroke values (S_{max}) for a wavelength equal to 1.47 m

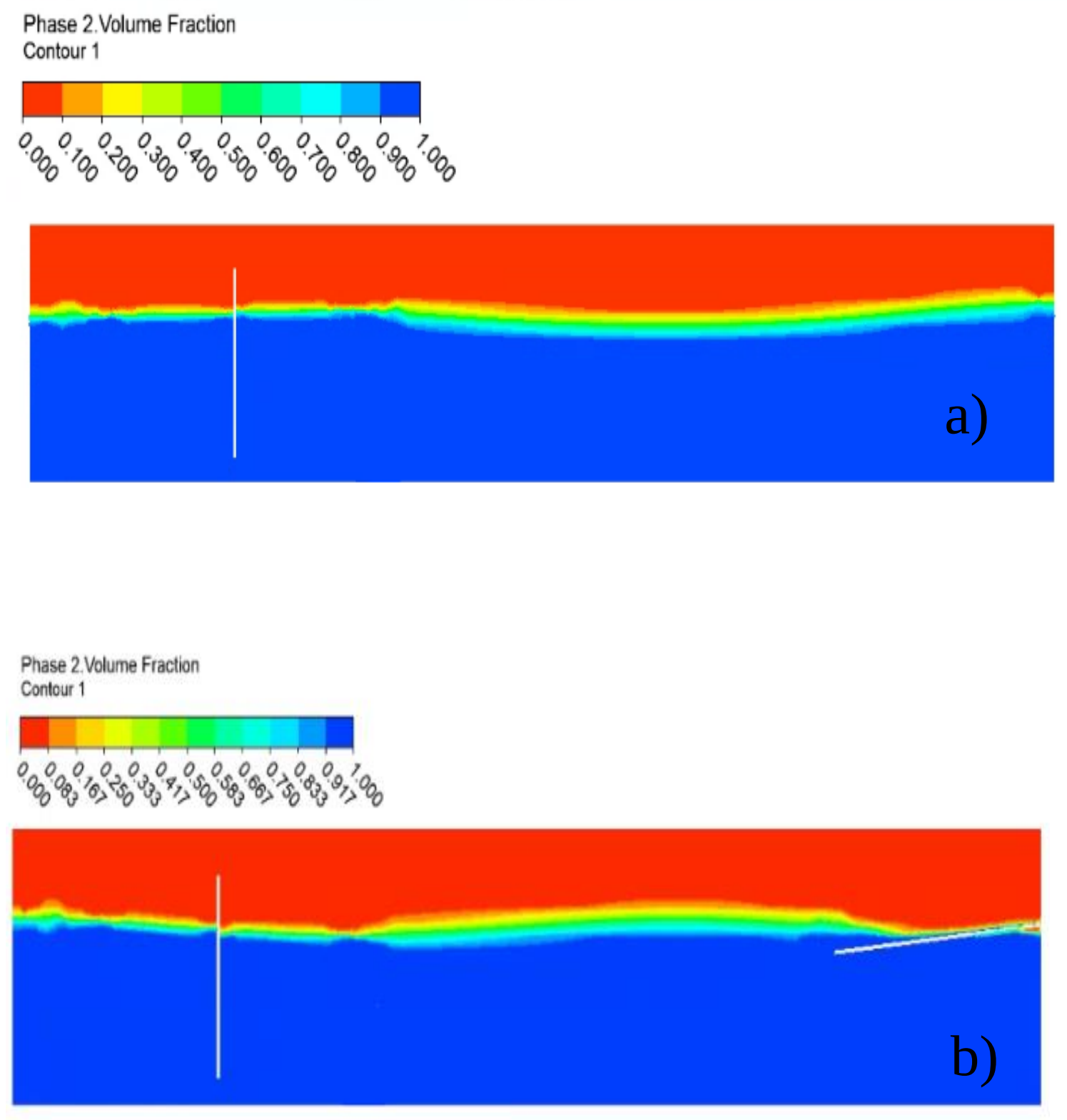
$$\frac{H}{S} = 4\left(\frac{Sinh\,(kd)}{kd}\right)\left(\frac{khSinh(kd) - \cosh(kd) + 1}{Sinh\,(2kd) + 2kd}\right)$$

Due to the space limitations in the laboratory where the channel will be installed, the maximum value of L that can be reproduced in the channel was defined to be equal to 1.47 m



Numerical simulation of the wave channel. Computational domain used for the numerical analysis

Results and discussion

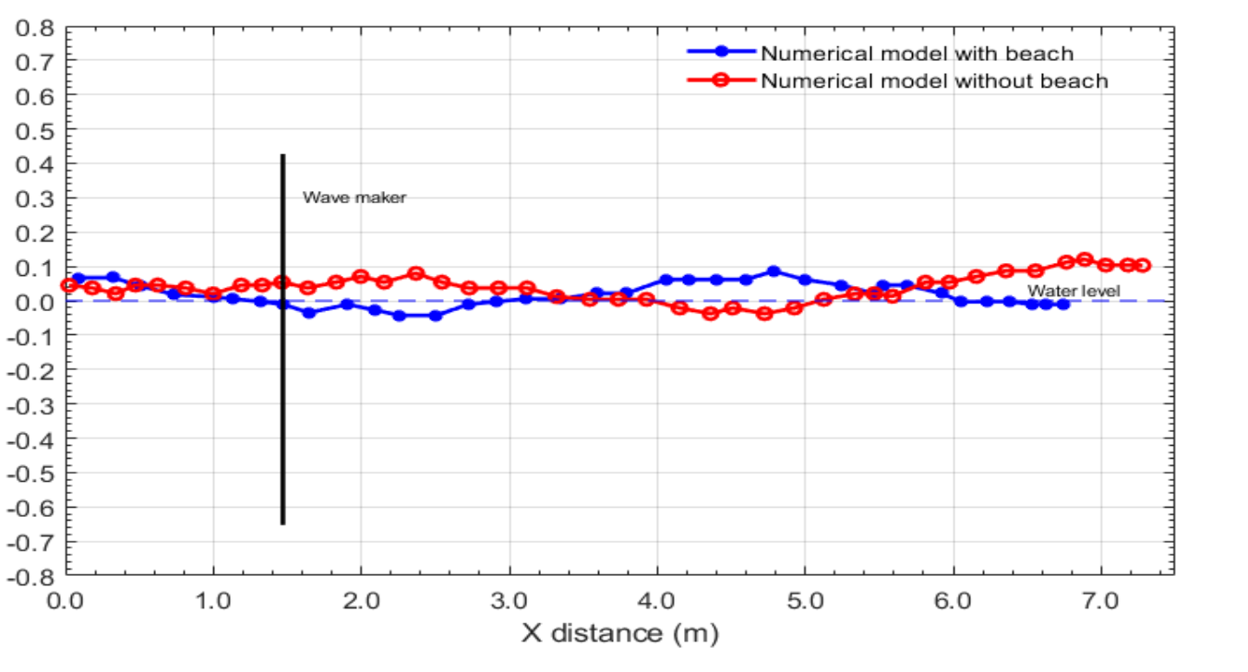


Volume fraction of the fluid in the wave channel. Numerical model a) with and b) without beach.

During the simulation, the propagation area was determined to be approximately between 2.5 and 6.5 m from the left wall of the channel. In this zone, once the wave is fully developed, it travels along the channel without suffering any significant modification on its wavelength, period, height or shape.

This is the appropriate zone to carry out experiments with WECs.

The wave channel designed can be widely used to analyse the behaviour of new WECs at small scale and representative sea conditions, such as those ones of the Pacific Ocean in Colombia because of the relative low cost and great effectiveness.



A good correlation of the water surface elevation profile and the expected wave H of 0.1 m for the simulated numerical case can be observed in the figure. The beach used in the extinction area enabled the wave energy to be dissipated, reducing the wave reflection considerably. This fact was characterized by the reflection coefficient, which is the ratio of the reflected wave H to the incident wave H. From the numerical results, the minimum value of the reflection coefficient was 0.12, which implies a significant reduction of the wave energy.

Conclusion

In this study, a wave channel was designed for testing WECs. The wave tank has been sized based on the dynamic scaling of wave characteristics from the Colombian Pacific Ocean. The selection of the wave tank components and dimensions is dictated by the nature of the wave formed to be simulated. The channel had a tested section measuring in 7.35 m, 0.49 m and 1.47 m (length, wide and depth, respectively), and it can be operated up to a water depth value of 0.8 m. Different types of waves can be generated by adjusting the water depth, the flap velocity and the stroke length. In the channel, a wave with T, L and H equal to 1.048 s, 1.47 m and 0.1 m, respectively, can be obtained from the wave simulation. In this regard, the determination of the vertical position of the crests is possible, which allowed to calculate the wave H, showing a reasonable match to the expected H of 0.1 m.

With the designed WEC, Colombia could take profit of the energy contained in waves, leading to a sustainable development achievement.

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